Quality of Service Aware MAC Protocol for Cognitive Radio Based Wireless Body Area Network

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A Thesis submitted in partial fulfillment of the requirements for the Degree of Bachelor of Science in Computer Science and Engineering.

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August, 2016

DECLARATION

We, hereby, declare that the work presented in this project is the outcome of the investigation performed by us under the supervision of,IffatAnjum, Lecturer, Department of Computer Science and engineering, BRAC University. We also declare that no part of this project has been or is being submitted elsewhere for the award of any degree or diploma.

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ABSTRACT

Wireless Body Area Network (WBAN) is envisioned to provide a wide range of health-care services to patients in medical environment such as hospitals and clinics. This increases the deployment of wireless platforms in medical environment that bring new challenges, such as interference with neighboring medical devices and the degradation of Quality of Service (QoS) performance, which may be critical to patient's safety. Cognitive Radio (CR) is next-generation wireless communications, and artificial intelligence has been widely adopted to provide self-learning in order to observe, learn and take action against its operating environment. The application of CR in medical wireless environment can cater to the aforementioned challenges. To address various application-specific requirements in CR-WBANs, several MAC protocols have been developed for WBANs and CRNs separately but very few Mac protocols have been proposed for CR-WBAN in the literature. Here, we propose a QoS aware medium access protocol (MAC) for CR based WBAN, with dynamic super-frame structure and effective channel availability prediction model.

ACKNOWLEDGEMENTS

Most importantly, we are appreciative and communicating our thankfulness to Almighty who offers us His heavenly gifts, tolerance, mental and physical quality to complete this venture work.

We are profoundly obligated to our venture chief Iffat Anjum, Lecturer, Department of Computer Science and designing, BRAC University. Her insightful direction, essential proposals, perpetual persistence, steady supervision, significant feedback, and huge measure of work for going through our drafts and remedying them from the earliest starting point to the end of the research work has made the fruition of the task conceivable.

Last but not the least; we are very appreciative to our guardians and crew individuals for their backing and consistent consolation, which have dependably been a wellspring of awesome motivation for us.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In recent times, advancements in wireless sensor networks have enabled them to support a wide range of applications, including medical and healthcare systems. A wireless body area network (WBAN) is a special-purpose sensor network designed to operate autonomously to connect medical sensors and appliances located inside and outside the human body and is used for long-term health monitoring within a hospital or remotely. A WBAN consists of biomedical sensor nodes used to monitor physiological data, such as temperature, blood pressure, electrocardiogram (ECG), electroencephalography (EEG), heart rate, *etc.* [1]. The key requirements of WBANs are low power consumption, negligible electromagnetic interface with the body, low delay, high reliability and effective communication.

Because of the spectrum scarcity problem recently encountered in wireless communication domains, cognitive radio (CR) technology has emerged as a key technique in wireless networks, including fifth-generation mobile networks. CR technology is a promising technique for unlicensed users to access underutilized licensed (or white space) spectra. It enables unlicensed users (or secondary users (SUs)) to opportunistically access underutilized licensed spectra whenever the licensed users (or primary users (PUs)) are idle [2].

In this paper, A Cognitive Radio Network (CRN) based solution for a movable Wireless Body Area Network (WBAN) has been proposed. We explored both the reliability and delay constrains requirements in QoS provisioning while maintaining energy efficiency. We proposed a preamble sensed & priority based MAC protocol for our Wireless Body Area Network that characterizes the information packets produced by respective applications in light of their QoS necessity. At that point we organized the information or data packets utilizing data class, data size and data generation rate. We developed the data transmission system within WBAN and from WBAN to

CRN such that, priority requirement, energy efficiency is maintained and system consistency is also ensured.

1.2 Wireless Body Area Network (WBAN)

Wireless Body Area Network has significant effect in the advancement of health care applications; at the same time there are some constraints which control the applicability and reliability of it. Although there is drastic advancement in sensor technology in this century, still they are battery powered. So, energy consumption for processing and data transmission of sensor nodes should be controlled. As used in Medical application, reliable and timely delivery should also be maintained strictly in WBAN. For example, data generated from an operation theater should be transmitted immediately, without any loss. Therefore QoS provisioning is an important issue in Wireless Body Area Network. There is existing literature that addressed some of these constraints, however very few of them addressed all the constraints.

In this thesis, we investigate both the reliability and delay constraints in QoS provisioning while preserving the energy efficiency. We developed a MAC protocol for Wireless Body Area Network that classifies the data packets generated by medical application based on their QoS requirement. Then we prioritized the data packets using data class, packet size and data generation rate. We designed the transmission mechanism such that, energy efficiency is maintained, ensuring consistency in network.

1.2.1 WBAN Architecture

WBANs usually use a star topology with a communication range of around 3 meters [3] and the sensors normally need to transmit information at particularly huge variety of data quotes from 1 Kbps to 1 Mbps [4]. The sensor nodes would need to be self-contained and battery operated and also ought to be capable of collect facts from a particular part of human body.

There are some conflicting difficulties in the building configuration of WBAN like quality of service awareness, interference avoidance and delay constrains, energy efficiency and organized data transmission. The sensor nodes are battery controlled. So when the system is framed they ought to be in full power mode, and the topology and protocol design ought to be such that all the challenges are met.

WBANs are comprised of a variable number of autonomous electronic devices, with components that has the capability of remote sensing, signal processing and communication in an ad-hoc fashion. Current sensor networks can exploit technologies not available 25 years ago and perform functions that were not even dreamed of at that time. Also sensors, processors, and communication devices are all getting much smaller and cheaper. Commercial companies such as Ember, Crossbow, and Sensorial are now building and deploying small sensor nodes and systems. Continuous encouragement on the development of technologies and algorithms for short range networks ensures that more capable and versatile sensor nodes are coming.

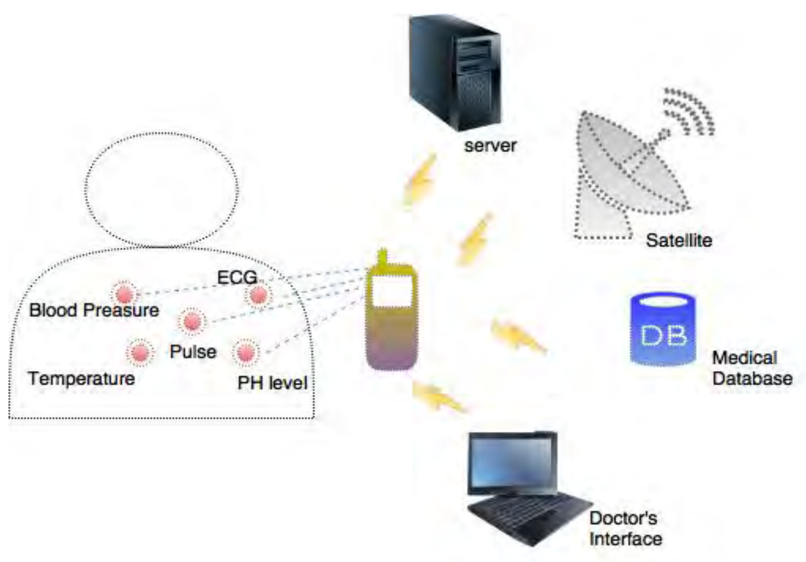

Figure 1.1: A General WBAN Architecture

1.2.2 WBAN Applications

The availability of small, low-cost networked sensors blended with advanced signal processing and information management is bringing a revolution in physiological tracking device. Wireless body area networks (WBAN) are allowing technology for improved healthcare, enhanced sports activities and fitness education, novel lifestyle tracking, individualized security and lots of different sectors.

- **Education sector:** The Rogers research institution, Illinois College is growing the in-body sensors and implants for cardio and neural activities and artificial eyes [5]. Those sensors need to send their records to an external medical server wherein it may be analyzed and stored. Using a stressed out connection for this purpose can be too large and involves a high value for deployment and protection [6].
- **IT sector:** WBAN allows continuous monitoring of the physiological parameters. Whether or not the affected person is within the medical institution, at domestic or on the move, the affected person will now not need to live in bed, but could be capable of flow round freely [7].
- **Medical sector:** With the help of recent improvements in clinical technologies the vice versa of the traditional methods are enabled. The new healthcare version encourages the use of inattentive clinic care, specialists and domestic healthcare to assist in far thrown affected person checks.[8] [9].
- **Safety to Auto-Driving:** Early identification of driver diversion can diminish the number of disasters. Movement locator sensors are utilized to distinguish leg and head developments of the driver [10].
- **Safety to Deep Sea Diving:** WBAN is also utilized in beneath-water diver fitness tracking. In this tracking machine, sensor devices are mounted on diver's body which could monitor the breathing, blood pressure, body temperature, mussel movement and so forth [11].

A WBAN is relied upon to be an extremely valuable innovation with potential to offer extensive variety of advantages to patients, medicinal work force and society through constant checking and early location of possible issues. Orderly, these advancements will convey us more like a completely operational WBAN that goes about as a pioneer for enhancing the Quality of Life.

1.3 Cognitive Radio Network (CRN)

A cognitive radio network (CRN) is an intelligent radio network that can be programmed and configured dynamically. Its transceiver is designed to use the best wireless channels in its area. Such a radio automatically detects wireless communications in a given spectrum band at one location [1,7] available channels in wireless spectrum, then accordingly changes its reception parameters to allow more concurrent. They can then adjust their transmitting parameters, such as power output, frequency, and modulation to ensure an optimized communications experience for user.

Now-a- days, wireless communication technologies and sensor are very rapidly spreading and evolving in many different field as well as medical service. The healthcare sector is an ideal example of how cognitive networking and cognitive radio (CR) techniques can be employed to enhance the robustness, scalability, and utility of medical equipment and systems using wireless communications. [2]

There are many definitions of CR which are still being developed in academia as well as through standard bodies, for example, IEEE-1900[12], SDR Forum [3] and FCC [4].

The following definition have been published in Report of International Telecommunication Unit (ITU) [13], "*Cognitive Radio System (CRs) is a radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained*".

1.3.1 CRN Architecture

There are two important capabilities that differentiate the CRNs from the traditional wireless networks are the converting spectrum environment and protecting the transmission of the PUs. The components of the CRN architecture can be labeled into the following two lessons [14], the basic additives of a CRN are shown in Fig. 1.2

- Primary network is the present network inclusive of the primary users (PUs) and PU base-station, in which the PUs have the license to function over a selected channel.
- CR community does not have any license to a particular band and consequently, special mechanisms and additional functionalities are needed for sharing the licensed bands by means of the secondary customers (SUs). Each CRN can have a fixed infrastructure, base-station (BS), to coordinate the SUs.

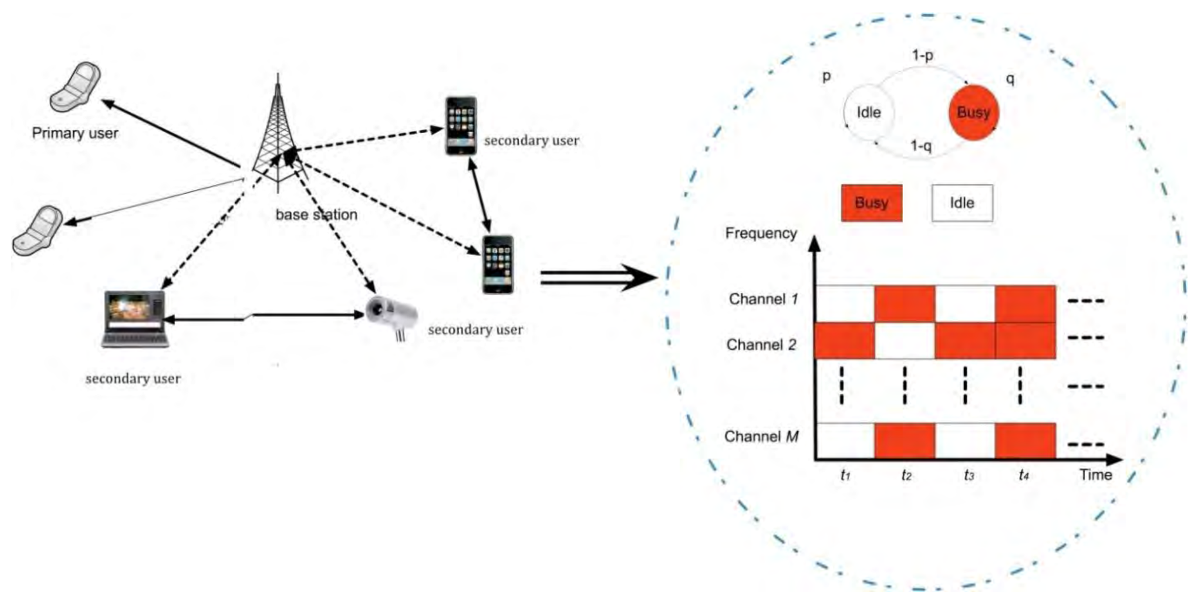

Figure 1.2: A Basic CRN Architecture

1.3.2 CRN Applications

There are many emerging CR networks applications based on CR technologies. This special issue is focused on presenting state-of-the-art research results on the application of CR networks. This is targeted for the innovative and productive discussion on the recent advancement in the application of CR networks and future directions.

- **Disaster Relief and Emergency Networks:** Hurricanes, Sedor, earthquakes, wild fires this type of natural disaster or other unpredictable phenomena generally cause the communications infrastructure to collapse, CRNs can be very useful then [15].

- **Public Safety Networks:** It is another type of networks that can be benefited through Cognitive Radio Networking [14]. Public safety networks are used for communications among police officers, fire workers and paramedic personnel.

- **Educational sector:** Through the low cost opportunistic usage of spectrum bands educational sector can be also benefited in CR networks, especially it can be highly benefited for the under-developed countries.

- **Wireless sensor networks (WSNs):** It can provide data transmissions with high QoS, implementing the cognitive radio capabilities. Cognitive radio-based sensor networks (CRSNs) provide a new paradigm for WBANs which is more efficient and opportunistic resource [16].

- **Battlefield Military Networks:** The reliable and secure communication network between the soldiers and armed vehicles can be established by the CRN [17]. Moreover its dynamic nature has the potential to track and jam a communication more difficult.

- **Machine-to-machine Communications:** It is an emerging trend in future wireless communication era, which will be highly benefited by cognitive radio.

1.4 MAC protocols in Cognitive Radio enabled WBAN

A number of MAC protocols have been proposed for WBANs, but few had been developed for CRBANs. Therefore, the improvement of a MAC protocol for CRBANs is a promising location of research. On this paper, we survey and compare recent advances and development trends in MAC protocols for CRBANs and then cope with open research problems and challenges. The main issues that ought to be addressed through CR-aware MAC in CRBANs are as follows,

Spectrum Access: The spectrum handovers aren't issued; due to the fact the transmissions of SUs are seemed to be noise through the PUs. Coordinated spectrum get entry to presents better spectrum usage and less interference than uncoordinated spectrum get admission to, because of the cooperation between radios via the alternate of real-time spectrum records.

Energy Efficiency: There are several attributes to be taken into consideration for the layout of an effective, dependable and electricity-efficient MAC protocol. the principle intention is to attain strength performance. For lengthy-term operation, it is necessary to minimize strength dissipation.

Cross-Layer Design: Spectrum sensing is done via the PHY and MAC layers; however spectrum management may be related to all different network layers.

Opportunistic Sensing: SUs experience a channel whenever they have got the possibility and keep a list of empty channels that is unbiased of other nodes.

Optimized Spectrum Decision: Numerous strategies and methods can be implemented for the getting to know and decision making methods, such as evolutionary computation, fuzzy good judgment and the Markov choice manner.

1.5 Problem Definition and Solution Methodology

1.5.1 Problem Definition

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Cognitive radio is a brand new generation that allows the extra flexible and efficient use of the radio spectrum. It lets in unlicensed customers to get entry to the radio spectrum without harmful interference with certified customers. A CR device intelligently adapts its spectrum usage via converting radio frequency in step with predefined getting to know parameters to pick out the first-class working frequency and transmission parameters. The industrial, medical and scientific (ISM) band is shared by means of various technologies, such as IEEE 802.eleven (Wi-Fi), IEEE 802.15.1 (Bluetooth) and IEEE 802.15.4 (ZigBee). These technologies operate and coexist in the equal frequency band, which may additionally cause interference among exceptional radio structures.

Issues associated with CR can span all layers of the conversation protocol stack. The principle functions of CR are spectrum sensing, spectrum get entry to and spectrum sharing and are frequently carried out by using the PHY and MAC layers. There are several differences between the CR-conscious MAC protocol and traditional MAC protocols. One is the variety of available channels, which varies with each time and spatial dimensions in CR networks, however is constant for each user in traditional networks. Furthermore, in CR networks, the MAC protocols ought to manage interference with PUs to guard them [15]. MAC protocols play a critical function in exploiting spectrum opportunities, collision avoidance, interference manipulate and avoidance for PUs and coordinating spectrum get right of entry to SUs.

1.5.2 Solution Methodology

In order to provide more reliable, efficient and QoS aware mechanism than the state-of-the-art protocols discussed in the previous section, we have to develop a MAC layer protocol that has three basic components. The components are Traffic Classification, Packet Prioritization, and QoS Packet Scheduling. The Energy efficiency is crucial for sensor nodes, so more devotion for increasing the battery life of the sensor nodes should be given. Classification of data packets based on their QoS requirements and urgency is also critical. Reliability critical packets should be sent such a way that they don‘t have to compete with others. On the other hand, when we are talking about delay critical packets, fast delivery is the more important to thing to consider. At the end traffic load of the environment should also be considered. We cannot address a sensor node with higher packet generation rate and another one with lower packet Generation rate in the same way as packet loss is critical in healthcare environment. The super-frame structure also has to be adopted with the changed protocol design and methodologies.

Among all the State-of-art Mac Protocols we have studied in chapter 2, PLA-MAC [18] is the most promising one for a WBAN system and PCR-MAC [20] for CRNs. So, with a little modification in appropriate places of PLA-MAC and using QoS aware CR technology in PCR-MAC for data transmission a CR based WBAN can be developed for addressing the dynamic environment issues for a portable CR based WBAN system. Our PCR-BAN MAC formulates a clever channel choice mechanism for every SU using a three-dimensional channel state sensing, channel availability prediction and QoS aware channel access mechanism is followed for the SUs on the basis of priority classification.

1.6 Contributions of this work

The major contribution of our work, priority based Quality of Service aware Wireless Body Area Sensor Network using Cognitive Radio technology, named PCR-BAN MAC [20]is summarized below:

- An energy efficient and load adaptive MAC for the communication between sensor node and BAN coordinator.

- The data packets are served based on their priority and the super-frame structure is dynamic.

- Auto-regression based channel availability model is used for effective licensed channel access between the coordinator node and central station.

- We have done a elaborate analytical analysis for comparing the protocol performances among PCR-BAN and other state-of-the-arts works.

1.7 Report Outline

The five chapters are labeled as Introduction, Motivation and Background, Proposed PCR-BAN Protocol and adopted WF-MAC Protocol in CRN. Performance Evaluation, Discussion and Conclusion. The outline of the thesis is as follows: Chapter 2 discusses background and motivation of MAC protocols, network model and their system goals and architecture. In Chapter 3 Our proposed PCR-BAN MAC protocol for a QoS aware CR based WBAN system have been discussed in details including their communication models, assumptions and MAC algorithm. The simulation scenarios and results are discussed in Chapter 4 and finally Chapter 5 with report summary and future goals concludes the paper.

CHAPTER 2

MOTIVATION AND BACKGROUND

2.1 Introduction

A number of medium access control (MAC) protocols have been proposed for provisioning QoS in WBAN. IEEE 802.15.4 [21], [22], [23] is a standard defining the specifications for the MAC layer of a low rate wireless personal area network(WPAN), which also provides a way for QoS provisioning in BSN. But the super-frame structure of IEEE 802.15.4 is not flexible and also the latency involved is high. BodyQoS [25] implements a virtual MAC to schedule and represent channel resources, which makes it radio-agnostic. But there is no priority consideration and also high computational complexity is involved. ATLAS [26] proposes a traffic load aware MAC protocol where the structure of the super-frame depends on the estimated traffic load. But it does not take priority into account. PNP-MAC [27] adopts the super-frame structure of IEEE 802.15.4. It proposes a MAC protocol with preemptive slot allocation and non-preemptive transmission and also takes priority into account. But it does not take traffic load into account; also duration of the CFP period of its super-frame structure is fixed.

2.2 MAC protocols for WBAN

2.2.1 IEEE 802.15.4 protocol (WPAN)

Despite the fact that the IEEE 802.15.4 [21], [22], [23] standard was particularly concocted to bolster low power, low information rate systems where inertness and bit rate are not all that basic, and as a reaction to the development in Wireless Personal Area Network, numerous prior works [24] embraced IEEE 802.15.4 MAC convention and its super-outline structure to bolster the QoS prerequisites of WBAN. From figure 3.2, we can see the super-frame structure of 802.15.4 comprises of a dispute access period (CAP), a dispute free period (CFP), and an idle period (IP). In the dispute access period, sensor hubs send demand parcels to the facilitator. The facilitator at that point apportioned openings for the hubs in the conflict free period which contains up to seven GTS spaces. The signal containing the space assignment data is transmitted to the sensor hubs in the following super-frame.

The CFP period contains up to seven ensured time openings (GTS), which restricts the dynamic conduct of BSN applications. Furthermore, IEEE 802.15.4 don't have any system for organizing among various applications, low need information can obstruct the transmission of high need one, which can bring about a serious issue in BSN. Thirdly, the asked for GTS time openings are not designated in the current super-frame; they are planned to the following super-outline, which expands the parcel delay on the other hand inactivity.

2.2.2 LDTA-MAC

LDTA-MAC [24] convention enhances a portion of the deficiencies of IEEE 802.15.4. The quantity of ensured time spaces (GTSs) is not settled, and they are apportioned powerfully in view of activity burden. Furthermore on fruitful GTS assignments, information bundles are transmitted in the current super-frame, rather than sitting tight for next super-frame and in this manner expanding bundle conveyance delay.

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2.2.3 BodyQoS

BodyQoS [25] isolates QoS scheduler from the basic MAC usage, a virtual MAC is produced here to make it radio-freethinker, permitting BodyQoS to plan remote transmissions without knowing the usage subtle elements of the basic MAC conventions. BodyQos does not experience the ill effects of the predetermined number of GTSs; it can adaptively plan transmission. The portion control and scheduler parts are actualized as an expert (aggregator) and slave (sensor) module. The primary piece of confirmation (allotment) control and the QoS upkeep carried on by the aggregator.

However, BodyQoS uses non-preemptive slot allocation schemes, so high priority data transmissions can be blocked by low priority transmissions. The aggregator (coordinator) initiated communication part is not energy efficient, as sensor nodes should be in listening mode all the time. Also separate MAC implementation can increase computational complexity of the aggregator and sensor nodes which are not acceptable as sensors nodes are battery powered.

2.2.4 ATLAS

Chart book [26] has proposed an activity load mindful MAC convention. It has embraced the super-frame structure of IEEE 802.15.4, taking diverse correspondence environment in record, and most proficient super-frame structure is picked powerfully taking into account the evaluated activity burden and correspondence environment. Map book has executed a multi-jump correspondence design.

Map book does not consider the need of various applications. There is likewise no sign of back-off class contingent upon the need to maintain a strategic distance from impact furthermore, to let higher need application to demand first. Likewise overseeing four kind of versatile super outline structure contingent upon movement burden might turn into a computational load on the entryway, influencing the general vitality and QoS necessities. As BSN is a little system conveyed over a human body, there is less need of multi-jump correspondence, truth be told it can turn into a computational overhead for sensor hubs.

2.2.5 PNP-MAC

PNP-MAC [27] convention depends on IEEE 802.15.4 super-frame structure. It can adaptably handle applications with differing prerequisites through quick, preemptive space distribution, non-preemptive transmission, and super-outline modification. By preemptive opening allotment, PNP-MAC addresses that the spaces as of now dispensed for low need bundle transmission can be acquired and designated to high need information bundles. What's more, by non-preemptive transmission, it addresses that crisis information, the most time-basic information are not transmitted in the spaces that are distributed for different sorts of information bundles. It likewise contains some exceptional guaranteed time spaces called crisis time slots (ETS) which are chiefly saved for crisis information bundles produced after the conflict access period.

As in PNP-MAC the term of CFP is settled, in the event that we have lower information rate, it will cause loss of time and vitality for being alert on this period. Again if the information rate is high then the altered latent period (IP) can bring about numerous critical and high need information to sit tight for the following super-outline. Again the CAP period just takes solicitation of GTS, not information parcels. For some application this time of postponement can be noteworthy. There is no harmony between the need thought and movement heap of sensor hubs. As low need sensors can have a higher activity load and they have more prominent back-off, they won't have the capacity to send the greater part of the information and drop them, which can bring about a noteworthy issue in restorative environment.

2.2.6 PLA -MAC

In this Mac protocol, a priority based MAC protocol for body sensor networks has been developed that modifies the super frame structure of IEEE 802.15.4. It has a dynamic super frame structure depending on the variation of traffic loads. Based on the delay and reliability constraints of data packets we primarily perform a traffic classification. Using this classification and data generation rates from sensor nodes we calculate the different *priority* and *back-off* values. The priority class is used by the coordinator while allocating slots for data packets. The back-off values are used by the sensor nodes to perform prioritized random back-off before transmitting the data packets.

In PLA-MAC [18], mainly data priority and load adaptability of data packets has been addressed. Besides packet delay and energy efficiency has been controlled to some extent but it did not considered the dynamic coexisting environment change around its BAN network which can create interference for its data transmission to outside networks through gateway. So, it can be best utilized for a static or non-movable Body Area Network in a constrained environment. Besides, the hardware complexity for the body sensors has also been ignored here.

2.3 MAC protocols for CRN

In the state of the art, many research works have focused on evolving CR-MAC protocols to boost spectrum utilization. However, the coexistence of CR networks with overlapping frequency spectrum has received less attention. Game theoretic approaches [32] are developed to minimize the interference in coexisting CRNs. Flexible mandatory access control (FMAC) [19] is a pioneer work considering coexistence property as a whole that addresses the dynamic availability of channels and proposes fair MAC protocol for CCRN environment. It allows the crowd of coexisting CRNs to share the channels effectively and achieves usage fairness.

However, without any knowledgeable channel selection mechanism and QoS awareness of diverse data traffic, the FMAC [19] fails to provide satisfactory performance in coexisting network environment. The FMAC users also suffer from channel starvation since they do not explore alternate available channels. Therefore, in CRNs there are some basic mechanisms that needs to be address by the cognitive users which are follows as:

2.3.1 Opportunistic Spectrum Sensing

The problem of isolating an efficient spectrum sensing policy among the SUs, has been widely addressed in the context of CRNs. The sensing efficiency of the network-wide spectral opportunities depends on when and how many SUs sense the channels, and how they collaborate or share those information. For instance, a distributed learning base probing technique has been adopted in [28] exploiting only a subset of available frequency bands. Compressed sensing [28], randomize sensing [29] and probe by sampling [30] techniques are also proposed in literature. Another effective policy for maintaining a cooperative environment, following a distribute-and-collect policy of the sensing load among the neighboring SUs for PU detection is addressed in the article of [31]. However, all the aforementioned techniques follow two state sensing models and fail to differentiate whether the channel occupancy is caused by a PU or SU, this information can play a crucial role in an over-crowded, bazaar environment of coexisting cognitive radio network. A distance estimation based three state sensing model is proposed in the paper of [37].

2.3.2 Common Control Channel Selection

To improve spectrum efficiency, many operations such as sharing data in cooperative spectrum sensing, broadcasting spectrum-aware routing information, and coordinating spectrum access rely on control message exchange on a common control channel [42]. Thus, a reliable and "always on" common control channel is indispensable. Since the common control channel may be subject to primary user activity, the common control channel design in cognitive radio networks encounters unprecedented challenges. The authors of [43] try to cope with the time- and space-varying nature of channel availability in CRNs, consider a cluster-based assignment of the control channel.

CRs are grouped in the same cluster if they roughly sense similar idle channels and are within communication range, either directly or via a cluster head. An always-on, out-of-band common control channel (CCC) design is proposed in [44] that uses noncontiguous OFDM subcarriers placed within the guard bands separating the channels of the licensed spectrum. An energy-efficient in-band common control channel selection mechanism, called $E2C3$ [45], through creating multi-hop clusters in a distributed manner. ETCH [46] proposes an efficient channel-hopping-based MAC-layer protocols for communication rendezvous in CR networks, both synchronized and distributed mechanisms are presented.

2.3.3 Opportunistic Spectrum Access and Sharing

The spectrum access problem is to determine how the resources to be used for an upcoming transmission, which includes both the identity of the spectrum to be used alongside a transmission, scheme to be used. On the other hand, the spectrum sharing problem considers multiuser scenarios and jointly allocates the available resources among different secondary users. Due to the close relationship between the two problems they are generally addressed jointly.

2.3.4 Distributed Spectrum Access

In a more related context, several distributed spectrum management schemes have been proposed for Ad-hoc Cognitive Radio Networks. The authors of OMC-MAC [29], represent a distributed channel allocation scheme and also a QoS aware medium access policy. The designs of PMAC [27] and PCR-MAC [20] are mainly emphasized on designing Synchronized MAC protocol for distributed CRN (DCRN) along with a channel selection mechanisms using EWMA-based historical usage prediction. They have also taken care of the traditional hidden node and exposed node problem. The PCR-MAC also exploits the idea backup channel adopted from SWITCH [21], with prioritized channel access. The authors of [27] present a price-based spectrum management framework for CRNs, modeling a non-cooperative game and using a price-based iterative water-filling algorithm to reach Nash-equilibrium.

2.3.5 Centralized Spectrum Access

Infrastructure based CRN provides more flexibility in characterizing incumbent usage pattern and designing spectrum access policy of unlicensed users. The two-level [31] MAC protocol maintains a simple probabilistic PU detection mechanism for channel allocation with a CR-CSMA or CR-ALOHA based packet scheduling framework. It studies the trade-off between the achievable performance of the secondary network and the protection effects on the primary network and designs the optimal frame length accordingly. A PU arrival rate prediction and channel holding time estimation structure is presented in [24],

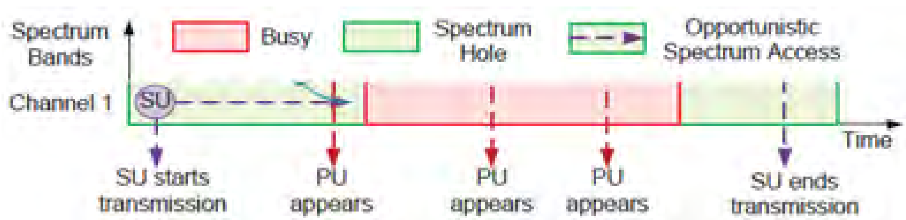

Figure 2.3: Opportunistic Centralized Channel Access by SUs protecting Incumbent

SUs takes channel access decisions using those statistics and a adaptive three holding policy. For the arrival rate prediction it uses SARIMA (Seasonal Auto-Regressive Integrated Moving Average) model. Alongside of dynamic spectrum availability, the authors of [48] also include QoS awareness in spectrum decision framework. In the paper of [49], a joint admission control and resource scheduling policy is proposed based on Layapunov optimization techniques.

2.3.6 Spectrum Access for Homogeneous Coexistence

The aforementioned protocols entirely avoid the concept of coexistence among multiple CRNs. Homogeneous coexistence or self-coexistence refers to the coexistence of networks that employ the same wireless technology [26]. The authors of ESC [50] propose an efficient channel assignment taking into account the overlaps among WRANs (Wireless Regional Area Network) to minimize interference. Several game-theoretic approaches has been proposed, like [30] and [51] tries to acquire a clear spectrum chuck free of interference from other IEEE 802.22 networks with the help of a spectrum band switching game where networks try to minimize their cost. Other learning based approach, like [34] strategize their action based on rewards obtained from the accessed spectrum bands. All them formulate the problem as a non-corporative game and establish the Nash equilibrium.

2.3.7 CR to Vehicular Ad-hoc Networks

Vehicular ad hoc network (VANET) and CR networks together opens up new opportunities in communication world, channel allocation problem is the most interesting and well investigated research issue in this area. Despite there are many channel allocation mechanisms proposed for VANET, and we already have discussed several on CR networks, a very few works have been done in the context of cognitive vehicular ad hoc network (CR-VANET). The unique features of both vehicular environment and cognitive radio network need to be taken into account while designing the spectrum management mechanisms for CR-VANETs [25].

2.4 MAC Protocols for CR-WBANs

In this section, we compare and discuss the MAC protocols designed for CRBANs. In Table 1, the MAC protocols reviewed in Section 3 are compared with respect to the collision ratio, channel access parameters, energy consumption, advantages and limitations.

In [15], packet transmission for critical nodes was prioritized over that for non-critical nodes by using the concept of cognitive radio. Critical packets were transmitted with higher power, whereas non-critical packets were transmitted with lower power. As a result, the throughput of critical traffic was higher than that of non-critical traffic. The packet collision ratio was low because of the preference accorded to critical traffic over non-critical traffic. According to the performance results of network throughput and the packet rejection rate, CR-MAC [15] provided QoS support for traffic with different priorities.

In DCAA-MAC [16], the channel access mechanism is performed on the basis of energy detection. To provide energy efficiency, each node goes to sleep and wakes up periodically and independently. The main advantages of this protocol are low latency, energy efficiency, configurability and no synchronization. Furthermore, the fast channel switching mechanisms provide QoS for CRBANs through low latency. Energy detection is useful in detecting the signal when the noise level is known. By implementing feature detection in CRBANs, the presence of PU signals can be effectively determined by extracting specific features of traffic.

C-RICER [17] works cognitively and energy efficiently in high-interference environments. The interference level of a wireless channel is measured by using RSSI values. To prevent coexisting interference, the affected working channel is adaptively switched to the lowest-interference channel. The data collision ratio is low because of the continuous sensing and switching of channels. The main feature of C-RICER is that it senses interference only in the current channel rather than the entire frequency band in order to reduce energy consumption. To render the system more reliable and energy efficient, the rescan cycle time should be adapted according to the interference duration.

In MBAN MAC [20], the cognitive capabilities are implemented in the network controller. The main features of the protocol are low power, low complexity and low cost with highly reliable communication. The protocol is energy efficient, because of the use of IR-UWB. In [20], several cognitive radio techniques were applied to UWB MBANs to improve coexistence with other systems through frequency agility and frequency domain spectrum shaping.

HCVP [26] provides an evaluation environment that provides a closer approximation to practical situations than other network simulation tools. Channel estimation is based on RSSI values, which are measured during the sensing period. The packet collision rate is reduced and the throughput is greatly improved when the CR algorithm is introduced. HCVP is a good solution to realize practical network scenarios by integrating software and hardware. Moreover, it is easier

to deploy and configure than FPGA-based platforms. By choosing low-power SoC chips, HCVP achieves energy-efficient performance and is suitable for testing power-critical applications.

Among the five MAC protocols designed for CRBANs, MBAN MAC [20] may be the primary choice when the target application area is remote healthcare monitoring. For example, patients are continuously monitored by sensors embedded on their bodies, and the sensed data are collected by a WBAN coordinator. The data collected by the WBAN coordinators are transferred to a remote monitoring system. The protocol resolves different issues and efficiently exploits cognitive radio technology. Furthermore, the protocol can adopt IEEE 802.15.6 for communication in intra-WBAN and ECMA-368 for inter-WBAN tiers. Further, the ECMA-368 MAC provides a distributed reservation-based channel access mechanism, as well as prioritized contention-based channel access

2.5 Summary

In this chapter, the key operation principles of a number of medium access control layer protocols for BSN, CRN and CRBSN have been discussed. Also in above discussion we have addressed our scope of work by indicating the performance requirement of medical environment, and level of service requirement fulfilled by existing works.

CHAPTER 3

PROPOSED PROTOCOL: PCR-BAN MAC

In the previous chapter, we have discussed about state-of-the-art MAC protocols for WBAN, CRN and their collaboration efforts, also defined the motivations and scopes of this work. In this chapter we will introduce our proposed protocol and its mechanism in providing QoS provisioning and Energy Efficiency for a CRN induced WBAN.

3.1 Introduction

In this project, we endorse a priority based MAC protocol for Wireless Body Area Networks (WBAN) that improves the super-frame shape of *IEEE 802.15.4*standard. It has a dynamic super-frame structure depending on thevariation of traffic loads. Predominantly, we perform a traffic classificationbased on the reliability and delay constraints of the data packets from sensor nodes. This dynamic traffic classification will help the body sensor nodes to transmit their data packets to the Body Network Coordinator (BNC) node. After that, it will be the responsibility of the BNC to make the sensitive medical data reach a central Base Station (BS), which will eventually transmit the data to concerned servers, clouds, doctors etc. The patients may be in distant rural area, battle field or in any crowded environments where free licensed network set-up is rare. For those reasons and also for cost effectiveness we are using opportunistic network access mechanism for the BNC to BS communication that is, we are using Cognitive Radio Network.

3.2 Network Model and Assumptions

In the proposed PCR-BAN protocol, we assume that several biomedical sensor devices are attached to a human body; they can be on-body or implanted inside the body. The sensor nodes collect data biomedical data and transmit the data to a central coordinator node (BNC) using a star topology. The BNC canbe a Smartphone, a Smart-watch, PDA or any device with routing and processing capability, which will transmit the data to the external network. The sensor nodes are assumed to have limited energy supply and limited processing power. The BNC significantly have more battery and processing power than the sensor nodes. Therefore, it is desirable to push as much computation and communication overhead to the coordinator as possible.

We consider a Cognitive Radio Network environment for the communication between the BNC and central network entity which is a Base-Station (BS) in our case, as shown in Fig 3.1.We assumes that the CRN have several Primary Users (PU) in its vicinity. There are n number of Secondary Users (SUs), the BNCs are working here as the SUs. We also assume that, there are m numbers of licensed channels; each channel is conditionally and opportunistically accessible by the SUs in the environment. Each SU takes t time to sense a channel; we consider it as the sampling interval. The arrival pattern of any user (PU or SU) on a certain channel follows the Poisson distribution [13]. In Fig. 3.1, we can see the whole network architecture that we have considered in our proposed methodology.

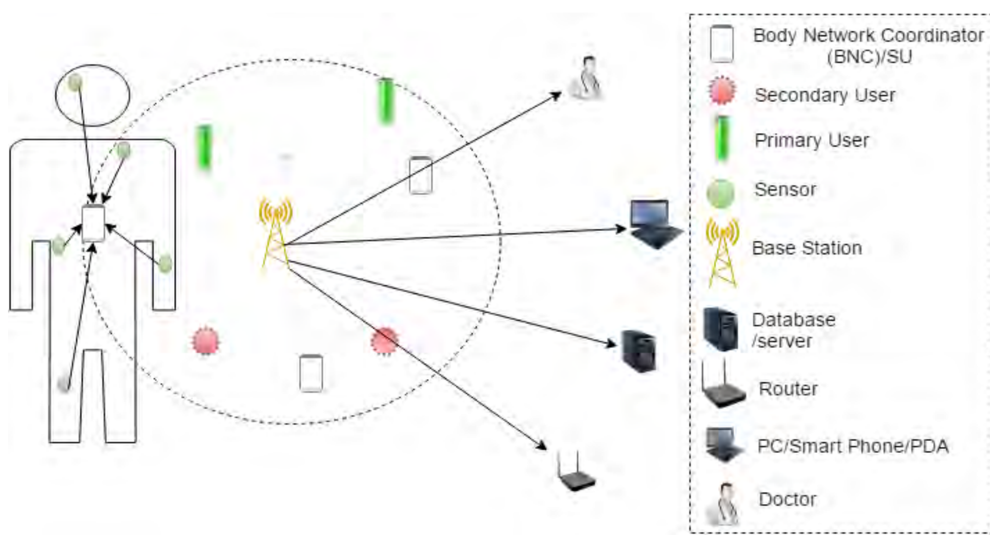

Figure 3.1: Proposed two layer CR-WBAN architecture

Notification or beacon from the coordinator is not considered significant. We assume that every data packet has a life-time T_{life}, specified by sensor nodes, which indicates the time limit within what the packet should be delivered to the BNC; otherwise, the information in the packet may become obsolete.

3.2.1 Traffic Classification for Biomedical Sensors

In this protocol, the generated information packets are divided in 4 traffic classes: Non-Critical data packets (NDP), Delay-sensitive data packets (DSP), Reliability-sensitive data packets (RSP), and Critical data packets (CDP).

- The NDP corresponds to data packet that consists of normal physiological measurements like body temperature, which don't have any serious reliability or put off constraints.
- The DSP packets correspond to packets that need to be delivered well timed, don't have a great deal reliability constraint, e. g. video streaming.
- RSP packets should be added with reliability that is with none records loss, but don't have any deadline, e. g. respiration monitoring, PH monitoring.
- The CDP packets have excessive reliability and postpone constraints; they need to be added with excessive reliability and occasional delay, e. g. ECG statistics packets. Note also that CDP packets involve higher data generation rate and packet size compared to other classes.
- Here the data packets are assigned a traffic class value ($\boldsymbol{\mu}_i$). Where the critical data packets are assigned the lowest and ordinary packets are assigned the highest traffic class value. Based on this traffic class value, the corresponding back-off and transmission priority values will be calculated.

Traffic Class	**Traffic Class value ($\boldsymbol{\mu}_i$)**
Critical data packets (CDP)	1
Reliability-sensitive data packets (RSP)	2
Delay-sensitive data packets (DSP)	3
Non-Critical data packets (NDP)	4

Table 3.1: Traffic class for QoS provisioning

3.2.2 Super-frame Structure

In the proposed PCR-BAN protocol, the super-frame structure is an improved version of the IEEE 802.15.4 super-frame the IEEE 802.15.4 [21] super-frame structure is shown in Fig. 1.2.Here, we have proposed the super-frame to have a dynamic structure; the length of the active part of the super-frame changes based on the traffic load in the network. The super-frame is assumed to contain a fixed CAP of 24 slots and the length of the super-frame is 128 slots. The number of CFP (Context Free Period) slots is not fixed, it will change with traffic intensity and the unused time slots will act as inactive periods.

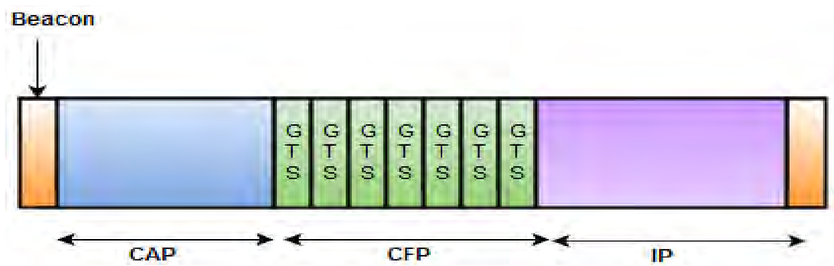

Figure 3.2: Super-frame structure of IEEE 802.15.4 standard

Our proposed, PCR-BAN super-frame structure includes five periods: Beacon, Contention Access Period (CAP), Guard Interval, Contention free Period (CFP) and Inactive Period (IP).

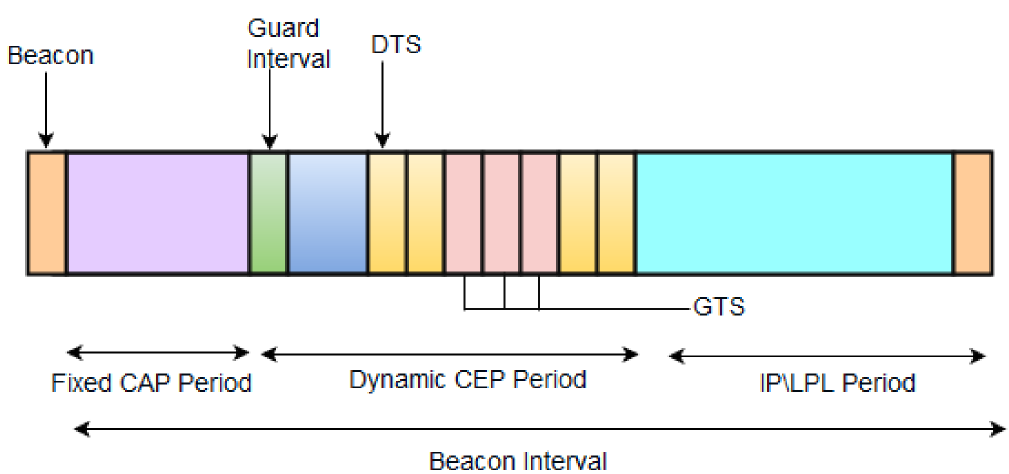

Figure3.3: Proposed Super-frame structure.

In Fig. 3.3, we can see that each super frame starts with beacon signal; the beacon informs all of the sensor nodes about the basic transmission facts of the coordinator node, and also indicates the beginning of the super frame. Inside the (CAP) slot, the allocation requests of the CDP, RSP and NDP (also can for DSP packets) class of packets for the (CFP) slots, and data packets of the DSP packets are received from sensor nodes. Whether a node will transmit a DSP packet or a DSP request to the BNC in CAP period, is up to respective sensor's implementation. After CAP period, the slots are allocated to the requested packets of sensor nodes according to their QoS preferences. Then the allocated slot numbers are notified to the respective sensor nodes and their transmission times in guard interval period. Then there is a CFP period, all through which the allocated packets are transmitted after the preamble sensing.

If the CFP does not occupy the complete super frame, then rest of the length is inactive period. The inactive period can be optionally used as Low Power Listening (LPL). Inside the CFP, there may be a percent of GTS that are kept for the emergency information packets which are generated after the CAP. The emergency packets can carry out a CCA to occupy the GTS. If generated in CAP it's going to transmit information through competition. If a sensor node cannot send the request for slots successfully at some stage in CAP duration, the transmission of packets from those nodes may be handled as follows,

- As defined in above, the emergency packets will be sent inside the GTS time slots, after doing a (CCA).
- For (RSP) and (NDP) packet types, they'll be stored inside the buffer of the corresponding nodes, waiting for slot allocation within the next super-frame. Such packets may be dropped if the node buffer overflows or packet lifetime (T_{life}) exceeds.

3.2.3 Channel Sensing Mechanism in CRNs

Each SU or BNC can methodically sense the channel states and identify the channel of being idle or busy [41], using Eq. 01. Each SU or BNC shares the sensing result through Common Control Channel with its base station (BS) that determines the channel states.

$$H_i = \begin{cases} n_i & 0, \\ (s_i + n_i) & 1. \end{cases} \quad (1)$$

Here, S_i is the received signal strength by an SU, and n_i is the additive white Gaussain noise (AWGN) with zero mean.

To maintain the licensed right of PUs, they should have higher priority than SUs. When PU wants to transmit over a channel and finds it in idle state, transmission will begin immediately. Now if the channel is occupied by SU, then to avoid the interference the PU should wait for a tolerable maximum time t_{max}, here $t_{max}<2\times t$. This allows the active SU to detect the PU arrival and release the channel, and look for other opportunities.

3.2.4 Control Information

Each SU or BNC is equipped with two transceivers. Both the transceivers can be tuned to one of the *m* licensed channel, first one is used for channel sensing and second one for the transmission of control information and data transmission. SUs exchange control messages over a dedicated common control channel (CCC). There are deferent approaches for transmitting control messages for CRNs and also for CCC selection, and it's totally application dependent. We are using three types of control messages for the operation of, shown in Fig. 3.4.

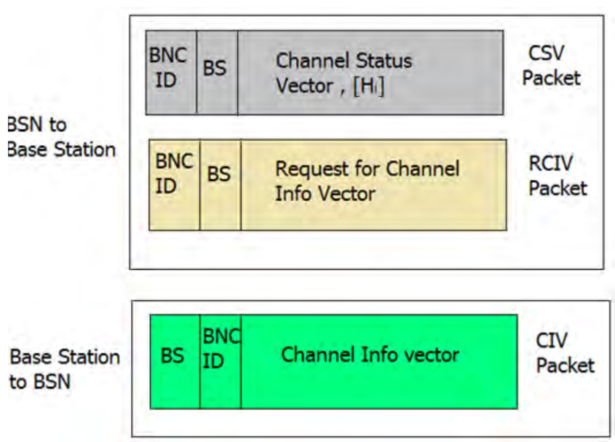

Figure 3.4: Control packets transmitted over CR-WBAN

- CSV Packet: It will contain the information of Channel Status Vector (CSV). Each SUs periodically sends this packet to its base-station, with the channel statuses sensed by it.

- RCIV Packet: Whenever an SU has some data packets to send and has not yet selected any channel for access, it will request for most favorable channel from its BS through RCIV (Request Channel Information Vector) packet.
- CIV Packet: After receiving RCIV the BS will send the selected channel for transmission.

3.2.5 Data Prioritization in CR Enabled nodes

We assume that each SU in the network is capable of running different types of application and generate packets with different traffic sensitivity [64]. The problem of ensuring adequate QoS demands comes down to prioritizing the data flows, recognizing and acting based on those. We classify the user traffic into four different traffic classes or priorities similar to WMM [65].

Type (Ω)	Description	Priority Range in BS	Priority Class(ρ) in BNC
WBAN	Highest priority (Low latency, e.g. voice call, audio streaming)	9-11	1
Entertainment	Second highest priority (Audio ,Video can buffer if needed, e.g. video conferencing, video streaming)	6-9	2
Best Effort	No QoS mentioned, or burst mode traffic (Traffic less sensitive to latency, but affected By Long delays. e.g. web surfing)	3-6	3
Background	Lowest priority (no strict latency, e.g. print jobs, email)	1-3	4

Table 3.2: Data Prioritization in CR Enabled nodes

Now, to discuss about the system architecture and assumption more elaborately the important notations and parameters used in our PCR-BAN MAC protocol definitions are listed in Table 3.1.

Notations	Description
$\boldsymbol{\rho}_{\mathbf{class}}$	Priority class value in BNC
$\boldsymbol{\Omega}$	Set of traffic types in BS or BNC
$\mathcal{C}_{\mathrm{i}}$	Set of selected licensed channels, { I = 1, 2, 3…….. N }
$\mathcal{R}_{\mathrm{i}}$	Channel Ranking
$\boldsymbol{\mu}_{i}$	Priority class value in sensor nodes
$\boldsymbol{\lambda}_{i}^{p}$	Primary user arrival rate
$\boldsymbol{\lambda}_{i}^{s}$	Secondary user arrival rate
$\boldsymbol{\beta}_{i}$	Max achievable data rate in channel i
t_{i}	Length of each time slot
$\mathrm{N_p}$	Noise power
$\mathbf{T}_{i}$	Expected total transmission time needed in channel, i
$\mathcal{P}_{\mathrm{n}}^{s}$	Transmission power of Secondary User, n
$\mathcal{P}_{\mathrm{m}}^{s}$	Transmission power of Secondary User, m
$\boldsymbol{\eta}$	Number of Secondary User
$\mathbf{B}$	Prioritized random Back-off calculation in BNC
$\mathcal{E}_{i}$	Channel availability prediction
$\varepsilon_{i}^{\mathcal{P}}$	primary user arrival rate in channel i
$\varepsilon_{i}^{\mathrm{S}}$	Secondary user arrival rate in channel i

Table 3.3: Notations and definitions used for CR-WBAN

3.3 Protocol Operation

3.3.1 Communication Model between the Sensor Node and BNC

The WBAN super-frame structure has been designed to be flexible relying on the traffic need. Each super frame starts with a Beacon signal. After the Beacon signal, the contention access period (CAP) starts, in which the nodes with CDP, RSP and NDP type data packets that make requests for DTS slots using a Prioritized random back-off mechanism, which will be discussed elaborately later in this section. CDP and RSP data packets are send using the reserved time slots due to the fact they are loss-sensitive. On the other hand, the loss-insensitive DSP type data packets content with every other packets to be transmitted inside the CAP slot. In CAP, the receiver node (BNC) sends back an ACK (acknowledgement) packet after a packet is successfully received.

The sensor nodes may additionally request for DTS slots for sending DSP throughout the contention free period (CFP), depending on the application's need. The requests for DTS slots that have been received in CAP are first looked after via the BNC node primarily based on their priority values and then allotted therefore. The coordinator node sends this allocation information to all nodes within the guard interval duration and hence the sensors get to recognize whether or not their requests have been granted or not; it also informs the slot number, if a request is granted. Consequently, there is no need of sending ACK for each request; the guard interval period does that part.

A Prioritized random back-off is performed by the sensor nodes for transmitting data packets in the CAP period. A sensor node, that sends either a data packet or a transmission request packet, performs a random back-off. The back-off value is chosen using following equation,

$$V_{back-off} = [0, 2^{\mu_i+2} - 1] \qquad (2)$$

Here, μ_i is the traffic class value. With this back-off mechanism, the probability of a critical data packet to enjoy less delay is higher than other data packets. As the back-off value is calculated based on the traffic class value, data packet that has lower traffic class value will get small back-off value and have to wait small period of time before sending a data packet or request. And data packets with higher traffic class value will get larger back-off value. For example, assume we have a critical data packet and an ordinary data packet to send. As traffic class value for CDP is 1, it will get a random back-off value between the range of [0, 7]. The traffic class value for NDP is 4, so its back-off will be in the range of [0, 63]. As in most of the case, NDP will have higher back-off value then CDP, so request of CDP will be sent before NDP.

A sensor node can sleep within the CAP period if it has nothing to send. The other nodes, after sending records or request packet, will visit LPL and wait for receiving any ACK (if data packet is sent) or notification (if request for DTS is sent). Those sleep and LPL periods save the energy of sensor nodes; also the BNC can go into sleep and periodically wake-up for channel sensing. In LPL, the sensor nodes may transmit emergency records packets only, depending on the implementation. Whether the IP or LPL may be activated can be determined dynamically by way of the coordinator node based on the traffic load of the network. Also, the IP might not be present inside the super-frame structure at very high traffic load conditions.

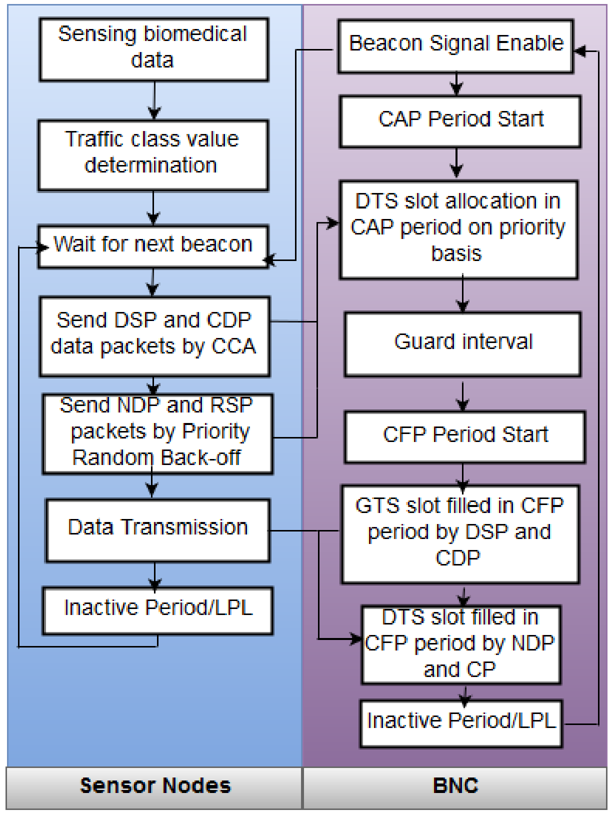

Figure 3.5: Communication model between the sensor node and BNC

We also keep provisions of transferring emergency packets during contention free period by allocating few Emergencies guaranteed time slots (GTS). More specifically, the GTSs are for transmitting emergency data packets that are generated after the CAP period. Here the number of GTSs can be calculated using exponential weighted moving average in the following way:

$$\eta_{GTS} = (1 - \alpha) \times \eta_{GTS} + \alpha \times \eta_{EDP} \qquad (3)$$

Here, the value of η_{GTS} is a weighted combination of the previous valueof η_{GTS} and the last value ofη_{EDP}, which is the number of emergencydata packets received in the last superframe. In this way, the number of GTSs will be dynamically adjusted during each super frame according to the number of emergency data packets received in the most recent super frame. So, the number of GTSs will increase when a large number of emergency data packets are generated and decrease when the number of emergency data packets goes down. The whole communication model is summarized in Figure 3.4.

3.3.2 Communication Model between the BNC and BS

The Following Figure below demonstrates the communication model suggested in our PCR-MAC protocol. BNC periodically sense the channel spectrum in CRN and send CSV (Channel Status Vector) to Base Station (BS). BS also periodically collaborate all the channel information and feedback provided by the all SUs present in the following CRN. Now, on the reception of a CSV packet from BNC, BS will determine the interference level and Signal to Noise Ratio (SNR), bandwidth and channel availability prediction to calculates the channel rankings, Ri∈C of the all the selected channel vector then BNC will determine whether a new data packet is transmitting at an admissible data rate and transmit power criteria in the R_{max} Channel selected based on the priority range value.BS will then deliver the CIV packet to BNC with selected channel information in it to start data transmission in this channel.

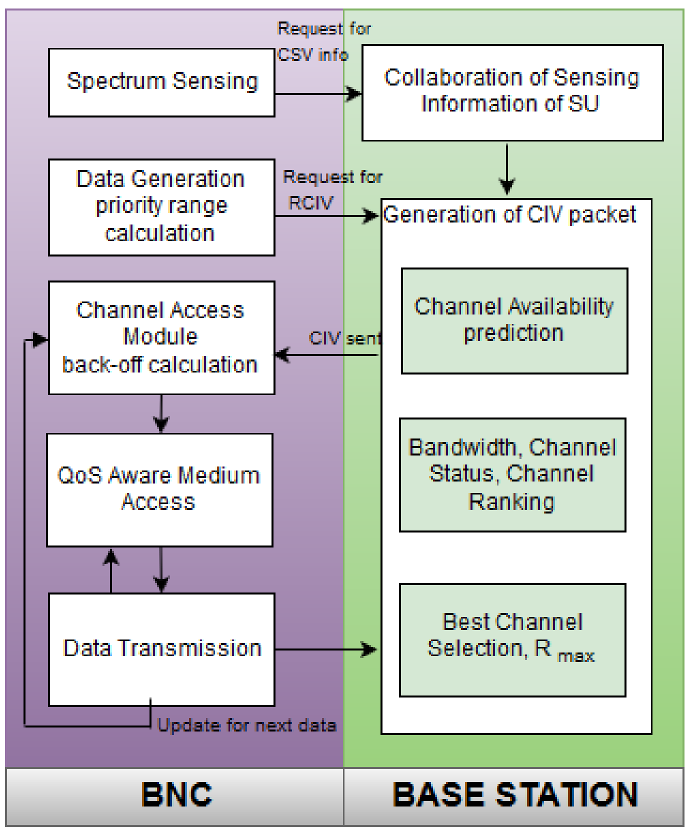

Figure 3.6: Communication model between the BNC and BS

3.3.2.1 Channel Availability Prediction

Our proposed infrastructure based CRN architecture follows Centralized CRN model in its functionality where Base station (BS) collaborates all the information containing experiences, feedbacks e.g. – primary user arrival rate in channel *i*, ($\lambda_i^{\mathcal{P}}$), secondary user arrival rate in channel *i*, ($\lambda_i^{\mathcal{S}}$), from all its SUs about all the licensed channels present within its network. So, gradually an effective and stable perception about each channel will be build up by the BS using its population's experience. Then after receiving this information the channel availability prediction vector, $\mathcal{E}$ will be predicted by the BS but not the SUs or BNC as happens in Distributive CRN model. So, to determine the channel availability prediction, the probability of no PU or SU will arrive during the whole data transmission period of BNC to BS will be calculated by the eq. [4] and eq. [5] respectively.

$$\mathcal{E}_i^{\mathcal{S}} = e^{-(\lambda_i^{\mathcal{S}} \times T_i)} \qquad (4)$$

$$\mathcal{E}_i^{\mathcal{P}} = e^{-(\lambda_i^{\mathcal{P}} \times T_i)} \qquad (5)$$

Where, T_i is the expected transmission time needed to transfer all the data packets from BNC to BS present in the buffer of BNC over channel *i*. Now, we can calculate the T_i from the eq. [6]

$$T_i = \frac{\ell}{\beta_i} + \mathcal{T}^d \qquad (6)$$

Here, ℓ denote the length of every single data packet, β_i denotes the maximum achievable data rate in channel *i* that can be calculated using Shannon's theorem [36] and lastly, $\mathcal{T}^d$ is the time delay between two consecutive data packets. Now the channel availability prediction vector can be calculated by eq. [7],

$$\mathcal{E}_i = \mathcal{E}_i^{\mathcal{P}} \times \mathcal{E}_i^{\mathcal{S}} \qquad (7)$$

3.3.2.2 Channel Selection Mechanism

According to the priority range value installed in the Base Station (BS) for WBAN types of data packets are from [9 - 11]. So, BNC node of a WBAN system will have to generate a value within this range and send it in the RCIV control packet to the BS so that BS after receiving the packet from BNC can recognize in which category it belongs to and then select an appropriate channel for that BNC node's data transmission operation. Now, the priority range value, $\mathcal{P}$ can be calculated by the eq. [8] ,

$$\mathcal{P} = 9+\left(\frac{\eta_{EDP}}{\mathcal{PW}_{battery}}\right) * (11 - 9) \qquad (8)$$

Here, the η_{EDP} denotes the no. of Emergency data packets data packets present in a super-frame of BNC that can be calculated from the derivation of eq. [3], $\mathcal{PW}_{battery}$ is the battery power condition of the BNC. Therefore, if the battery condition of BNC is low or number of Emergency data packets is high in the frame then this BNC will get the highest priority for data transmission due to its criticality by a contention based method (CSMA) in the selected channel from the BS than the coexisting WBAN's BNC within this network.

Now, to perform channel ranking calculation using eq. [11]. The Boolean model of SINR represents the possible interference due to simultaneous transmission of multiple nodes to a specific channel. When a BS r receives data from a specific SU n, all the other simultaneously transmitting SUs where $m \in N_r$ & $m \neq n$, interferes with it. So, BS will determine SINR value for each of its selected licensed channel by the eq. [9]

$$SINR_i = \frac{\mathcal{P}^{\mathcal{s}}_{n \neq m} \times d(n,r)}{\sum_{m \neq n}^{k} (\mathcal{P}^{\mathcal{s}}_{m} \times d(m,r)) + N_p} \qquad (9)$$

Here, Sn is the received signal power from SU n, S_k from SU m and N_p denotes the noise power. d(n,r) and d(m,r) are the Euclidean distance between the BS and SUs or BNC, can be defined as follows,

$$d(n,r) = \sqrt{(n_x - r_x) \times (n_y - r_y)} \qquad (10)$$

Whenever an BNC has some data to transmit, it sends a RCIV packet, RCIV = $[\mathcal{P}]$, containing priority range value, $\mathcal{P}$. In turn if the request is granted by the BS then it will send back the response CIV packet, $CIV = [R_{max}]$.

Now, Using RCIV, BS will generate the maximum ranked channel, R_{max} for BNC from a channel set of C_i, $\forall i \in C$. using eq. [11] and [12],

$$\text{Channel Ranking}, \mathcal{R}_i = \frac{\mathcal{E}_i \times \mathcal{P}}{SINR_i \times Ti} \qquad (11)$$

Here, T_i is the expected transmission time for a channel i which is calculated using eq. [5]. $\mathcal{E}_i$, is the channel availability vector for channel i determined by the eq. [7] and $\mathcal{P}$ denote the priority range value from BNC. The whole process of channel selection is summarized in Algorithm 01.

ALGORITHM - 01

Channel selection algorithm for BS, $n \epsilon C$

```
Initialize 𝓔_i, ,SINR_i& T_i   where, ∀ i ϵC
WHILE BS is active DO
IF receive CSV packet from BNC/SU DO
Collaborate received channel status information.
Calculate transmission time T_i using eq. [6]
Calculate channel availability vector 𝓔_i using eq. [7]
END-IF
IF receive RCIV packet from BNC/SU DO
Determine the priority Range value 𝒫 from RCIV packet  using eq. [8]
Calculate channel ranking value R_i using eq. [11]
IF𝒫_i>= 9 or 𝒫_i<= 11 DO
Determine the channel R_max with maximum R_i value
Send a CIV packet to BNC with selected channel info.
END-IF
END-IF
END-WHILE
```

3.3.2.3 Channel Access Mechanism

Now, the BNC will try to access the selected R_{max} channel i, by prioritized random back-off calculation to successfully deliver the data packets to the Base station and to avoid the collision with the PUs and other SUs while packet transmission. The equation is as follows:

$$B_{BNC} = \begin{cases} \left[2^{(\rho+1)} + t_i\right], H_i = 0 \\ \left[2^{(\rho+1)} * \ \delta + t_i\right], H_i = 1 \end{cases} \qquad (12)$$

Here, t_i is the length of each time slot over channel i, δ is the number of times transmission is blocked by the PU, ρ denotes the priority class value in BNC and finally, H_i is channel status that is when its value is zero, that means no PU will be detected during transmission and when its value is one that means channel detected an PU. However, the contention window is, CW = [1$-B_{BNC}$].

3.4 Summary

The proposed PCR-BAN MAC protocol provisions QoS to the data packets that transmitted from BNC to BS. The packets with higher priority gets small back-off value than the packets with lower priorities, which results in transferring critical data packets from sensor nodes to BNC ahead of other lower priority packets in the contention access period. We also kept provision of sending emergency data packets in CAP without asking for DTS as the higher precedence packets may additionally contain emergency information. Besides, The delay sensitive packets are also handled with this same mechanism. The reliability sensitive packets are transmitted in CFP length, so reliability is also ensured. Our super frame structure can adapts its CFP according to the traffic load as it is dynamic and the calculations for priority classification at the sensor nodes are kept to a minimal degree, So performance in power consumption is also maintained. Now to transmit the arrived packets in BNC to BS in through the CRN with maintaining its QoS constrains a priority range and its corresponding priority class has been developed on basis of which the BS will calculates the maximum ranked channel after some predictive analysis on the available licensed channels and ranking them in order of their availability and transmission strength and then provide it to the BNC for data transmission to begin with much better throughput. So, we can see that maximum complex calculations are being done in BS which we assume to be huge infrastructure but that much in the BNC which eventually leads to efficient power consumption in our WBAN system.

CHAPTER 4

PERFORMANCE EVALUATION

4.1 Introduction

In this section, we compared the performance of the proposed QoS aware and traffic load adaptive PCR-BAN MAC protocol with PNP-MAC [27] which is a state-of-art protocol for a WBAN system and CR-WBAN MAC [20] is a state-of-art protocol for a CRWBAN system. Here, we have conducted simulation using network simulator ns3. To analyse the performance of the studied protocols, we have compared them in the fields of average packet delay, throughput and energy consumption.

4.2 Simulation Environment

For the simulation of the aforementioned MAC protocols, we consider a CR based Wireless body area network consisting of a single coordinator called BNC and a number of biomedical sensor devices in WBAN and a single BNC and Base Station (BS) in the CRN . The sensor devices collect data and transmit them to the BNC using a single-hop star topology. Here we have used NS-3 (Network Simulator 3) for the simulation of the proposed PCR-BAN MAC protocol. The super-frame parameters used in this simulation are slot size = 7.68 ms, number of slots = 128 and the CAP size of proposed MAC protocol = 20. We consider the CFP size of the PNP-MAC [13] protocol as 40 slots in the simulation as there was no specific size mentioned in the paper. For the proposed PCR-BAN MAC protocol, we considered the number of DSP packets to be 20% to 30% of the total data packets, and the CDP, RSP and NDP packets to be the other 70% to 80%.The network parameters used here are summarized in table 4.1.The parameters used for evaluating energy consumption are given in table 4.2.

Parameter	Value
Channel data rate	250 kbps
Initial energy	100 joule
Number of nodes	varied to collect data(1-10)
Super-frame period	1 s
Number of slots in a super frame	128
Slot duration	7.68 ms
CAP duration in PNP-MAC	8 slots
CAP duration in proposed protocol	20 slots
CFP duration of PNP-MAC	40 slots
Simulation time	100s

Table 4.1: Simulation parameters

Operation mode	Energy Consumption
Transmit	10 mA
Receive	4 mA
Sleep	20 uA
LPL	1 mA

Table 4.2: Energy consumption parameters

4.3 Performance Metrics

The following four metrics have been considered for the performance evaluation of our proposed PCR-BAN MAC.

Average packet delivery delay: In our network there are several sensor nodes and a coordinator. Each of the nodes transmits packets, which are received by the coordinator BNC. Packet delivery delay here is the time between generation of a packet at a sensor node and its reception at the coordinator node in specific slot of the corresponding super-frame.

Throughput: In communication networks, throughput or network throughput is the average rate of successful packet delivery over a communication channel. This data may be delivered over a physical or logical link, or pass through a certain network node. The throughput is usually measured in bits per second (bps), and sometimes in data packets per second or data packets per time slot. In our evaluation, we have used kbps (kilobits per second); we have calculated the amount of payload bits carried in the total number of data packets received at the coordinator node.

BNC energy consumption: Coordinator energy consumption is the amount of energy consumed at its different states, like transmit, receive, sleep and low power listening states. As the architecture and orientation of the super-frame in PCR-BAN MAC is different than CR-WBAN MAC and PNP-MAC; there is a significant difference in amount of energy consumption as well.

4.4 Simulation Result

In our simulation performance evaluation, we have studied the impacts of the amount of traffic loads from different devices.

4.4.1 Impacts of traffic load

Now, we measure the performance of PCR-BAN MAC with respect to various traffic load. For this we assume there are a fixed number of node which is 7, and their traffic load will vary from 1 Pkts/s to 7 Pkts/s.

4.4.1.1 In Average Packet Delay

In figure 4.1, we perform the evaluation of average packet delivery delay with respect to diverse traffic load. We can see that PCR-BAN MAC shows a good result compared to the other protocols, especially in the higher traffic load section. The CR-WBAN [15] MAC experiences a large amount of delay and the delay increases with the increasing traffic loads. The PNP-MAC protocol shows lower delay than the CR-WBAN [15] MAC, but this delay is increased when traffic load is larger than the fixed number of GTS slots of PNP-MAC. The PCR-BAN MAC is capable to achieve consistent low packet delivery delay with the increasing traffic loads. This nice result is the artefact of traffic-load adaptive dynamic super-frame structure and special treatment of DSP packets defined in our proposed PCR-BAN MAC.

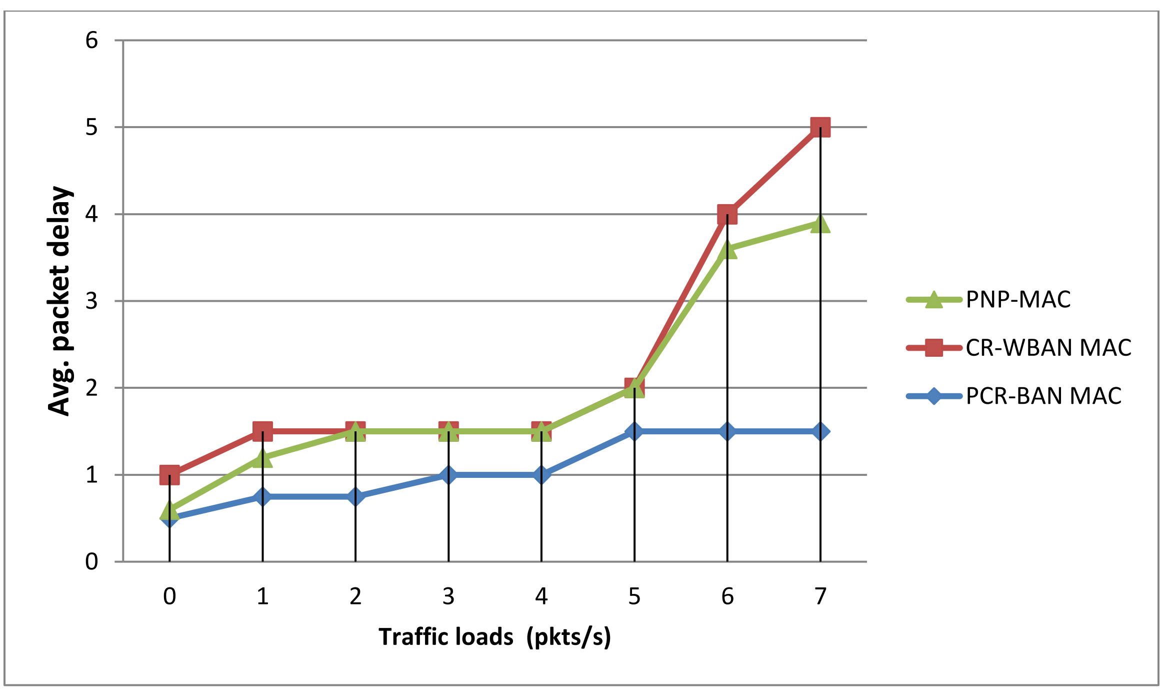

Figure 4.1: Average packet delivery delay versus traffic loads.

4.4.1.2 In Throughput

Next, we evaluate the throughput of the compared protocols in figure 4.2.

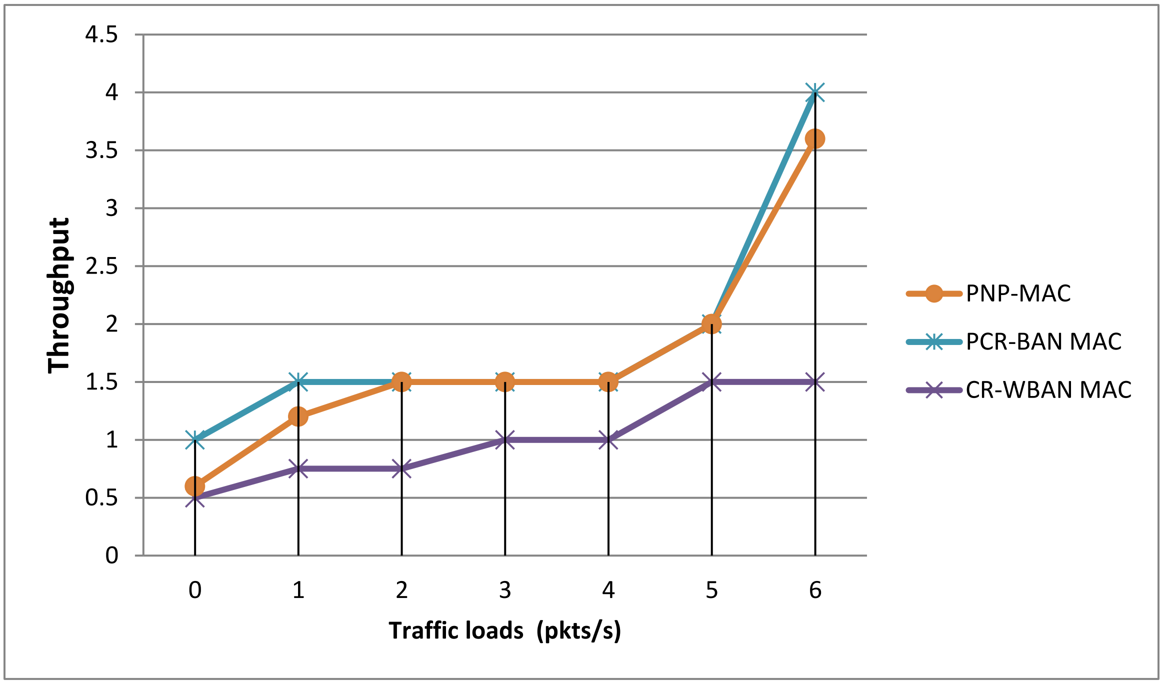

Figure 4.2: Throughput versus traffic load

We can see that PCR-BAN MAC achieves the maximum throughput of 16.3 kbps in the compared protocols. Here, as the CR-WBAN [15] MAC has only 7 GTS slots, so the throughput never increases from the first transmission. The growth of PNP-MAC also stops after the traffic load exceeds the fixed number of CFP slots. But because of the adaptive CFP period in PCR-BAN MAC, the throughput of the proposed protocol continues to grow gradually.

4.4.1.3 In Energy Consumption

In figure 4.3, we evaluate the energy consumption of the coordinator of the studied protocols. It presents similar results with that in figure 4.4. Here the CR-MAC and the PNP-MAC protocol shows a fixed power consumption, the reason being the fixed number of CFP slots in both protocols. But the PCR-BAN MAC protocol shows a varying power consumption depending on the amount of traffic load, as it contains a dynamic super frame structure with adaptive CFP period.

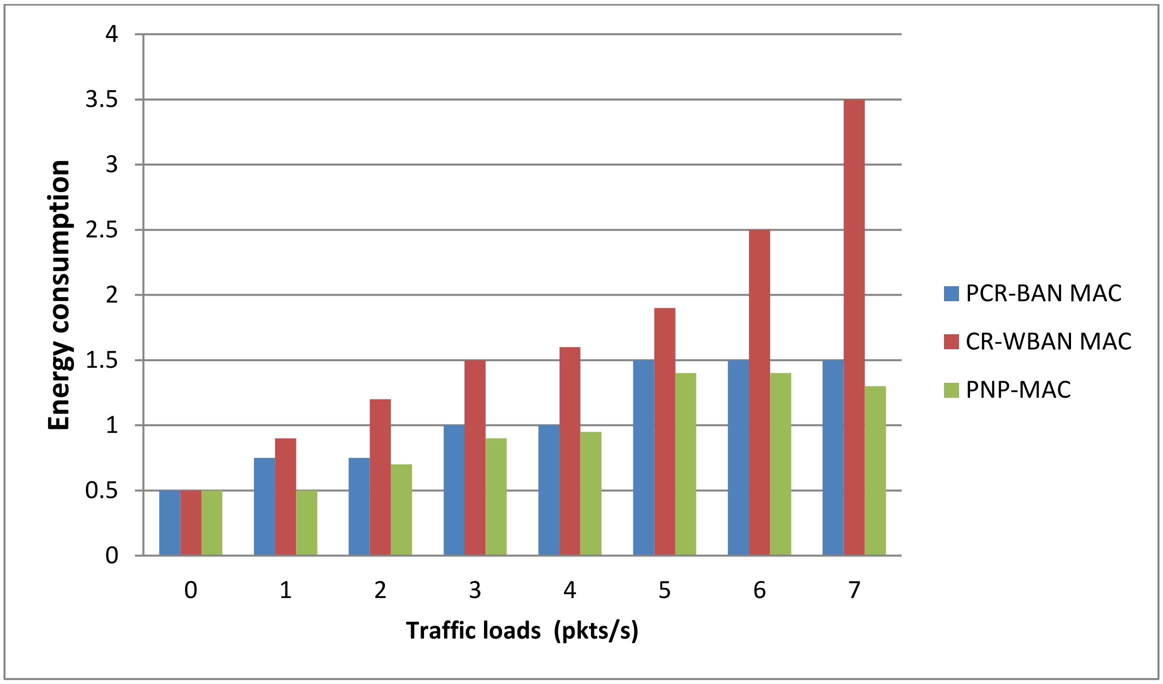

Figure 4.3: Energy consumption versus traffic load.

4.5 Discussion

From figure 4.3 we can observe that, PCR-BAN MAC consumes more energy than PNP-MAC mostly when the number of nodes is higher. Actually, there is a trade-off here between the network throughput and energy consumption of nodes. On the other hand CR-WBAN MAC is mostly higher power consuming as it has to implements the complex CR functionalities for its data transmission.

So, from figures 4.1 and 4.2, we can perceive that the achieved throughput of our proposed PCR-BAN MAC protocol is better than the other two state-of-the-art protocols and also the average packet delay is much lower than the other two. However, the energy consumption of the PCR-BAN MAC is little higher than the PNP-MAC as it has perform some calculations and also it has a dynamic DTS, So when the number of end devices is more than 8 or traffic load is higher it will get less IP/LPL period. Therefore, energy consumption is little higher than PNP MAC but less than CR-WBAN MAC.

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Summary of the project

In this paper, we develop a priority based PCR-BAN MAC protocol for CR-WBAN which uses an infrastructure-based coexisting CRN to transfer its necessary data to outside world that maximizes the system throughput and provide QoS provisioning in the delay and reliability domains, while preserving energy efficiency of the network. For the delay constraint, we provide multiple transmission option in the full super-frame structure.

The generated packet can dynamically decide where to send and how depending on their delay requirement. For the reliability domain, guaranteed time slots are used. These slots are allocated by the coordinator node to the sensor nodes where the allocation is based on the requests for transmitting data generated by the sensor nodes. And for delay driven packets which are sent in the contention period, acknowledgement packets are used for reliability.

For maintaining Energy Efficiency, sensor nodes are active only in the period when they have something to send, otherwise they go to sleep or LPL. Coordinator node also follow the same mechanism for energy saving. Traffic Classification has been done based on the QoS requirements of the generated data packets. For example, reliability critical packet and delay critical packets have been handled following different mechanism.

Delay driven packets and request for guaranteed data slots are sent in contention with each other. To avoid collision and data loss we have introduced prioritized random back-off based on traffic class number. As sensor nodes have small buffer space, PCR-BAN MAC assigns higher priority to nodes with greater generation rate and larger packet size. Traffic class is also considered in priority calculation, which gives the balance between QoS provisioning and data generation rate.

Emergency data packets which has the most critical delay and reliability requirement, has also been given special consideration. PCR-BAN MAC reserved some special emergency transmission slots on which emergency data can be sent without slot allocation. Number of emergency transmission slots is calculated using weighted moving average, insuring dynamic adjustment. Simulation results show that PLA-MAC can efficiently cater for the needs of various traffic types with different combinations of reliability and delay requirements. As a result, PLA-MAC can significantly improve the effective capacity of a body sensor network in terms of both energy and QoS requirements.

The developed multi-constrained QoS provisioning and energy aware scheme is expected to work providing good performance in BSN applications. However, it will not work well when data generation rate and their QoS requirements are too diverse. Its network diameter is small as it is designed for human body diameter. As a result it will not work well in large diameter.

5.2 Discussion

Analysing the state-of-the-art protocols in Body Sensor Network and Wireless sensor Network, and finding out the drawbacks from those works was the main focus for us. A Big challenge for us was to find out the alternative solutions and also the design and exploration of the implementation details of the alterative solution. Designing a useful super-frame from existing protocols so that we can meet-up all the QoS requirements, and also impose different classification on generated data traffics of the sensor nodes, all-in-one designing a QoS aware MAC was very challenging. We evaluated our proposed PCR-BAN MAC in network simulator-3 and compared its performance with other popular state-of the-art protocols, like CR-MAC,PNP-MAC. Evaluating our proposed mechanism in ns-3 was also a huge challenge.

In simulation, we extensively measured our performance and at the end of the evaluation part, we can say all of our hard-work and devotion paid-off when our proposed PCR-BAN MAC showed better performance from the others.

5.3 Future Works

We are currently working on the advancement of our protocol, to adopt it with upcoming IEEE 802.15.6 standard on 2013 [31]. IEEE 802 has established a Task Group called IEEE 802.15.6 for the standardization of WBAN. The standard defines a Medium Access Control (MAC) layer supporting several Physical (PHY) layers and also introduces security consideration in data transmission, like encryption and authentication. We are working on the implementation details of supporting several physical layers. For encryption and authentication part we will use any of the well-known algorithms. Some modification should also come in traffic classification, back-off calculation, and priority calculation section of our protocol. The super-frame structure may also go though some modification and enhancement.

The proposed PCR-BAN MAC protocol is described considering only a single-path and single coordinator-rooted network topology, even though a WBAN might consist of multi-path, multi-coordinator, and multi-tree topology. We will adopt those mechanism in our future work. This work can also be extended to the design of routing protocol from coordinator to end-devices. Although that will exceed the range of body sensor network, this work will give a complete specification for a medical network system or for other applications.

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